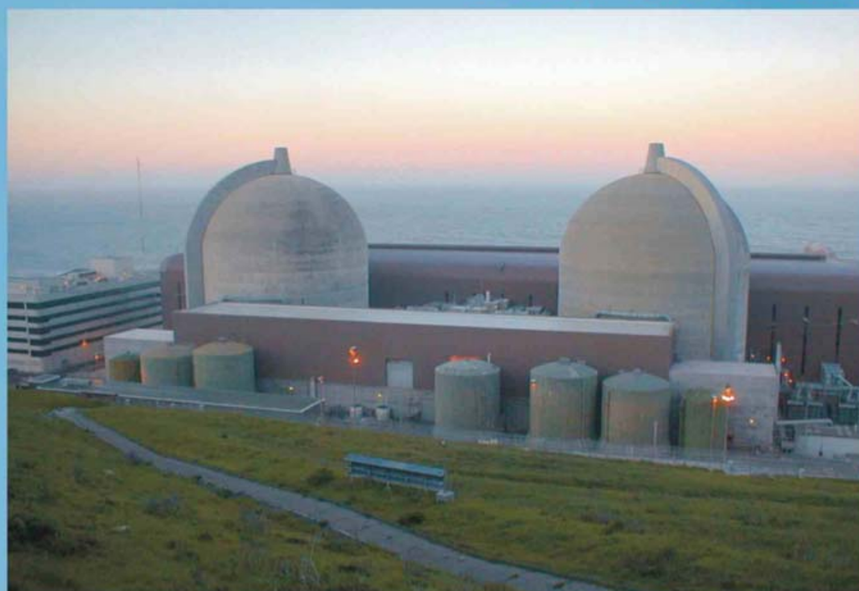
CVAP™ & COMMAND™

Check Valve Software



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INTRODUCTION TO CVAP & COMMAND
A Model for the Industry

The Check Valve Analysis and Prioritization Software (CVAP) and Database, assists in the identification, prioritiation and monitoring of check valve misapplications to optimize preventive maintenance through a systematic evaluation that focuses on maintenance resources on the “bad actors”. The underlying predictive models are based on rigorous testing and analytical research performed at Kalsi Engineering and reported in NUREG/CR-5159 & /CR-5583 and incorporated in the technical guidelines provided by EPRI NP-5479 *Application Guide for Check Valves.* The CVAP *blended* methodology simultaneously considers component specific design features, application specific flow disturbance and usage patterns and valve failure histories. CVAP models for predicting disc stability and internal wear rate are mature and ready-to-use and the software user friendliness has been improved through extensive plant application since 1988. These models have shown good correlation against observed, in-service degradation of check valves at power plants.

Industry check valve programs for SOER 86-03, INPO API-913 based Equipment Reliability Improvement Programs (ERIP), Condition Monitoring (CM) or Risk Informed (RI) programs require screening, grouping, and evaluating valves to (1) proactively identify and fix potential bad actors before they fail and, (2) to streamline maintenance. The Check Valve Analysis and Prioritization (CVAP) software and database can help these programs identify unreliable installations, prioritize maintenance and enhance the Preventive Maintenance program effectiveness by quantifying valves propensity for wear and tracking and trending inspection results.

CVAP is widely recognized as the premier software for check valve analysis and preventive maintenance prioritization and was called a "model" for the industry by INPO. CVAP is fully documented and has been verified according to Kalsi Engineering’s Quality Assurance Program, which meets 10CFR50 Appendix B requirements.

CVAP Benefits

CVAP offers cost savings, stability and continuity by allowing its users to:

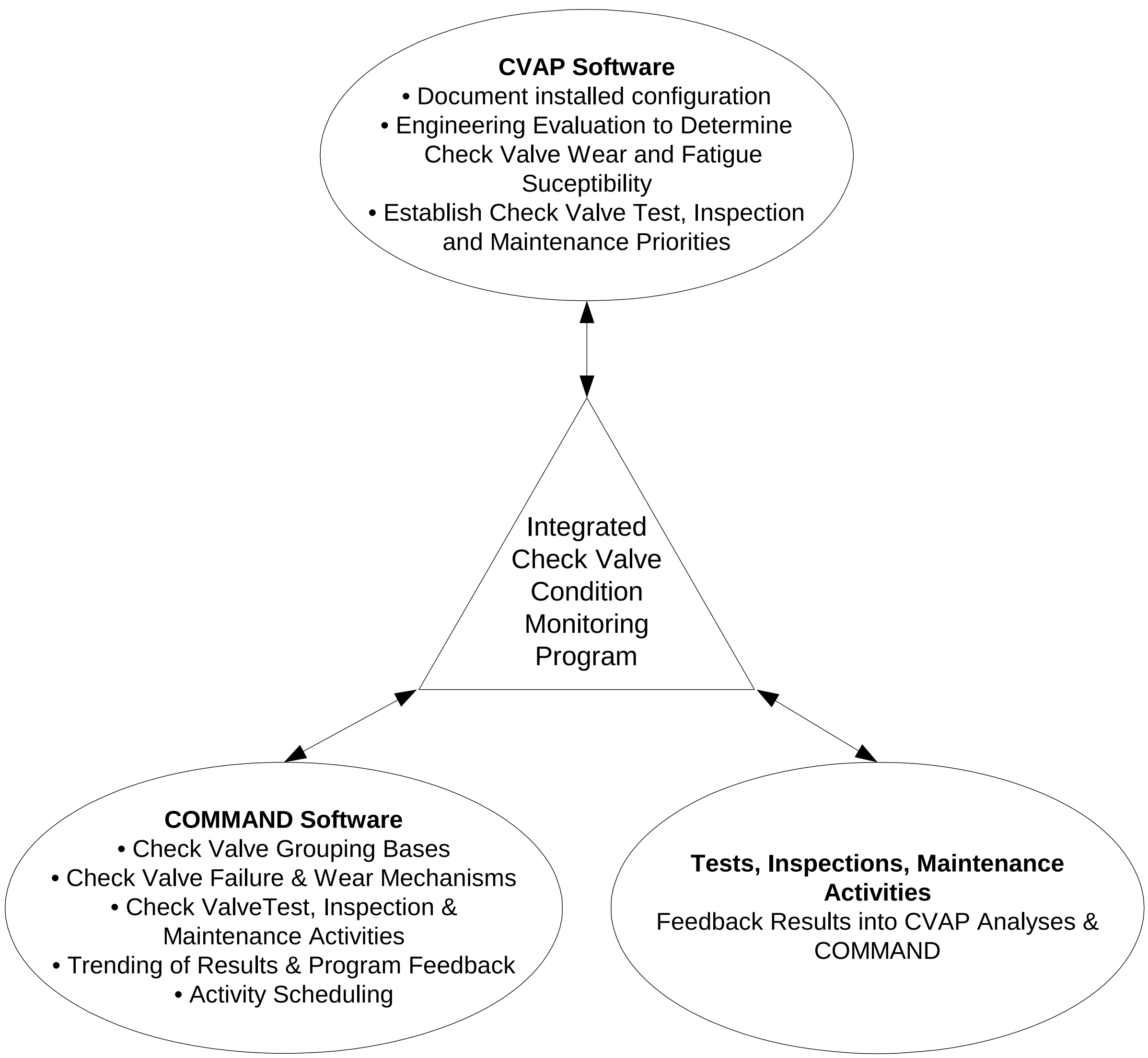
- **Reduce O&M costs and improve plant reliability** streamlining preventive maintenance activities - *reducing unnecessary disassembly and inspection of properly functioning valves and quantifying the wear rate for bad actors.*
- **Standardize and realize long-term cost savings** through data sharing and uniform implementation across fleet check valve programs. A typical outage involves 20-30 disassemblies at an average cost of $5000. The cost of disassembling all valves in a typical population of 300 valves over a 10-year period is $1,500,000 per plant. Reducing disassemblies by 50% can result in a savings of $750,000 per plant. Additional cost savings would accrue from improved plant availability, ALARA benefits and improved preparedness to support shortened refueling outages.
- **Upgrade check valve programs** with reliable predictions based on a methodology that is fully developed and ready to use. The software and database has been refined through

usage at over 3,000 check valve applications in 24 U.S. and Canadian nuclear power stations, since 1988.

- **Protect investment in valve calculations** by utilizing widely used software that is continually enhanced to address emerging industry needs of Equipment Reliability Improvement Programs, OM 22 Condition Monitoring and INPO SOER 86-03 program updates. For example, the need for baseline internal wear rate predictions and a database to track and trend inspection results to update previous scope based on an obsolete simplified Vmin formula (that assumes 20D of upstream straight pipe) and no wear quantification.
- **Retain and enhance plant expertise** by creating a controlled design database for tracking and trending and training in-house specialists. CVAP is backed by comprehensive software and valve hands-on training and technical support offered by Kalsi Engineering's highly capable specialists who have provided stability and continuity of services to our clients for over 25 years (average employee tenure is > 19 years).

The **Co**ndition **M**onitoring **Man**agement **D**atabase (**COMMAND**) software is designed to comprehensively meet the documentation and trending requirements of the ASME OM Code Mandatory Appendix II, "Check Valve Condition Monitoring Program." The COMMAND software addresses all program aspects including valve grouping, program analysis, optimization and performance improvement activity development, test/inspection intervals, trending and feedback, and corrective maintenance. In addition, the software includes a valve activity scheduling module, database query tools and hard-copy reports.

The graphic shown below describes how CVAP and COMMAND when used in conjunction with in-plant testing, inspection and maintenance activities can provide a truly integrated and efficient check valve condition monitoring program to the KHNP plants.



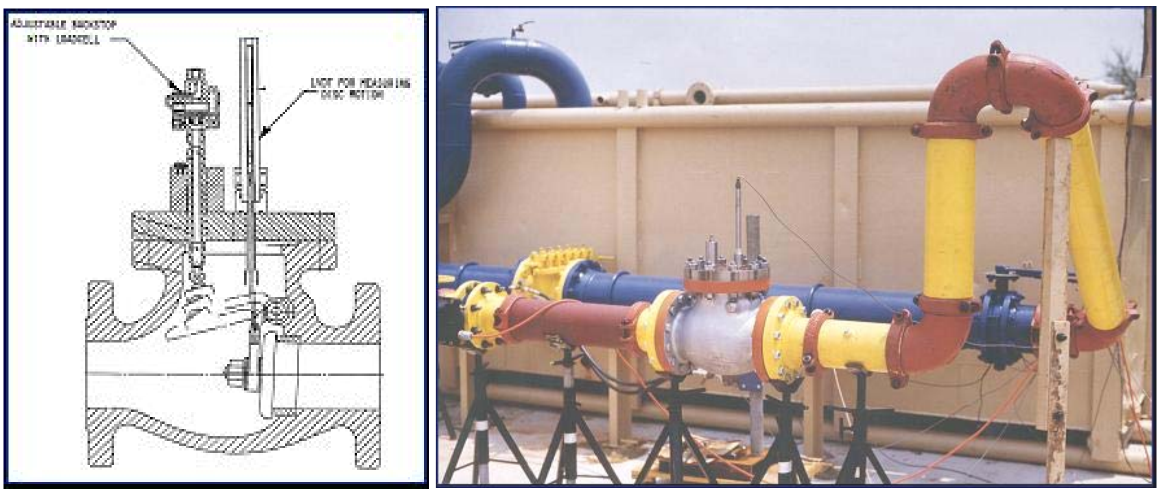
Plants with CVAP License / Calculations Performed by KEI

No.	Utility	Plants/Units	CVAP License	Calculations Performed by KEI
		U. S. Plants		
1	AmerenUE	Callaway	Yes	20
2	AmerGen Energy Co	Clinton Power Station		150
3	American Electric Power	D.C. Cook 1 & 2	Yes	279
4	Constellation Nuclear	Nine Mile Point 1 & 2	Yes	
5	Duke Power	Oconee 1, 2 & 3	Yes	
6	Duke Power	McGuire 1 & 2	Yes	
7	Duke Power	Catawba 1 & 2	Yes	
8	Entergy Nuclear Northeast	Pilgrim	Yes	
9	Entergy Nuclear South	ANO 1 & 2	Yes	150
10	Entergy Nuclear South	Grand Gulf	Yes	160
11	Entergy Nuclear South	River Bend	Yes	468
12	Entergy Nuclear South	Waterford 3	Yes	302
13	First Energy Nuclear Operating Co.	Davis-Besse	Yes	150
14	Florida Power & Light	St. Lucie 1 & 2		300
15	Florida Power & Light	Turkey Point 3 & 4		300
16	Florida Power & Light	Duane Arnold	Yes	
17	Florida Power & Light	Point Beach 1 & 2	Yes	
18	Luminant	Comanche Peak 1 & 2	Yes	200
19	Nebraska Public Power District	Cooper Nuclear Station	Yes	279
20	Progress Energy	Harris	Yes	87
21	PSEG Nuclear	Salem 1 & 2	Yes	317
22	PSEG Nuclear	Hope Creek	Yes	
23	Southern California Edison Co.	San Onofre	Yes	190
24	STP Nuclear Operating Co.	South Texas Project 1 & 2	Yes	200
25	Wolf Creek Nuclear Operating Co.	Wolf Creek	Yes	36
		International Plants		
26	Bruce Power	Bruce A 3 & 4	Yes	
27	Bruce Power	Bruce B 1, 2, 3, & 4	Yes	
28	SNN/Romania	Cernavoda 1 & 2	Yes	

Total Units: 38 domestic and 8 international

Background of Flow Loop Testing and Model Development Program for CVAP

Kalsi Engineering's development of check valve performance prediction models began in 1985 as it assisted Southern California Edison Company (SCE) in properly identifying the root cause of its swing check valve failures. Kalsi Engineering has since performed over 4000 dynamic flow tests on several instrumented check valves, including those with worn internals to develop empirical data to efficiently simulate various plant piping configurations. CVAP models efficiently apply this database of empirical data to predict disc stability and rates of internal degradation. The following are key milestones marking the evolution of the CVAP methodology:



A comprehensive matrix of flow loop testing was performed to develop models for Check Valves incorporated in CVAP.

Failure Analysis of Feedwater Swing Check Valves and Replacement Recommendations for San Onofre Nuclear Generating Station

Failure of five feedwater system check valves in November 1985 had resulted in a water hammer, over-pressurization of the low-pressure piping system, and damage of over $5 million. This was caused by accelerated fatigue and wear damage due to disc flutter and repeated hammering of the disc stud nut against the backstop during normal operation. Kalsi Engineering prepared a root cause analysis report for NRC and recommended replacement valves based on a generalized minimum velocity formula, which was developed during this investigation. Replacement valves were tested and found to perform satisfactorily as predicted. ASME paper No. 86-JPGC-NE-6, titled "Plant Availability Improvement by Eliminating Disc Vibrations in Swing Check Valves," was published as a result of this project. This marked the inception of the CVAP model development

The effort was expanded to include a thorough application review and inspection of 50 additional valves in various systems to determine the appropriate corrective action. This included valves from many different manufacturers with a wide variety of differences in installation details. Kalsi

Engineering, Inc., used the overall results from this effort, along with additional research, in the development of check valve application guidelines under the EPRI project.

Development of the Electric Power Research Institute "Guidelines for Application and Use of <u>Check Valves</u> in Nuclear Power Plants" and Subsequent Enhancement for the Nuclear Industry Check Valve Group

Kalsi Engineering was selected to develop industry guideline for check valve application by EPRI and an Owners Group Task Force consisting of representatives from all four NSSS suppliers based on its strong technical expertise in root cause analyses and solving many check valve and water hammer problems in nuclear power plants. Additional research, including instrumented check valve tests, was performed at Kalsi Engineering's flow loop to investigate the effects of upstream elbow proximity, orientation and turbulence sources. All available check valve performance detection techniques, e.g., ultrasonic, acoustic emission, high-energy radiography (portable accelerator), noise and vibration power spectrum analysis, were also evaluated. The final monograph was prepared jointly by Kalsi Engineering and MPR Associates. Under a separate project funded by the Nuclear Industry Check valve group, Kalsi Engineering contributed to the revision of this document that was coordinated by EPRI/NDE Center.

Development of Electric Power Research Institute "Guidelines for Application and Use of <u>Valves</u> in Nuclear Power Plant Systems"

Based on Kalsi Engineering's strong background in solving many complex valve problems at nuclear power plants, as well as our performance on a previous EPRI check valve project, EPRI selected us to develop a monograph on valves for nuclear power plant systems as a main source of reference for the nuclear utility engineer. Since a large percentage of unscheduled plant shut-downs costing utilities millions of dollars each year are directly due to valve/actuator operability problems, EPRI decided that an authoritative text on the subject would be helpful in avoiding or reducing common errors, root causes of failures, and misapplications. Through a nationwide solicitation of competitive proposals from many organizations, EPRI selected Kalsi Engineering and Stone & Webster, based upon their technical strength and competitiveness, to jointly prepare this document.

Development of Wear and Fatigue Prediction Techniques for Check Valve Performance Degradation under Project for Nuclear Regulatory Commission

Based on the background Kalsi Engineering, Inc., has in this area, NRC selected us to pursue further analytical and experimental work to develop predictive techniques for check valve disc stability and motion to quantify expected wear and fatigue damage during operation. The objective is to identify those valves in the system that will be subjected to accelerated degradation and may require frequent maintenance, design modification, or replacement. This approach allows us to prioritize and rank check valves with respect to their potential adverse effect on safety and reliability.

Kalsi Engineering has developed wear and fatigue prediction techniques that have been compared and found to correlate well with the check valve failure or degradation data available from several applications at the plants. The results of this work are reported in NRC report NUREG/CR-5159, *Prediction of Check Valve Performance and Degradation in Nuclear Power Plant Systems* and NUREG/CR 5583.

Condition Monitoring/Preventive Maintenance Based on Check Valve Analyses and Prioritization (CVAP®) Program

We have developed the Check Valve Analysis and Prioritization (CVAP) program, which is based upon extensive data from the EPRI Check Valve Guidelines developed by Kalsi Engineering; our root cause analyses experience from evaluating many failures; and though our continuing, systematic wear and fatigue testing on check valves at our flow test facility. CVAP allows us to perform a thorough, efficient, and very cost-effective analysis of various types of valves and provide *quantitative* information regarding relative degradation trends. This methodology has proven to be very useful in prioritizing valves from the standpoint of their adverse effect on safety and reliability as well as in developing a condition monitoring-based preventive maintenance program with suitable maintenance/ inspection intervals for each valve. This methodology referred to by INPO as a "model for the industry" has been used to analyze over 3,000 check valves at more than 22 U.S. nuclear power plants. It is a valuable resource for fulfilling the requirements for condition monitoring (ASME Oma Code 1996, ISTC 4.5.5, and Appendix II) and meeting the goals of the equipment reliability improvement programs.

CVAP Software Capabilities

The Check Valve Analysis and Prioritization Program and database is a state-of-the-art software that efficiently predicts disc stability and rate of internal degradation of common types of check valves.

CVAP includes a comprehensive database of test results to predict swing check valve oscillation amplitudes and frequencies under various installation\configurations and flow conditions. The flow loop test matrix to support CVAP development and validation included over 4,000 dynamic tests to cover variations in valve size, elbow orientation, elbow distance, flow direction, flow rates, and ΔP. CVAP provides disc stability and wear and fatigue predictions under baseline conditions and for upstream disturbance effects.

In many check valve applications, the CVAP models quantify the rate of internal degradation and provide an engineering basis to reduce unnecessary equipment maintenance. ***The CVAP database and the more accurate models have already demonstrated cost savings for the plants.***

From inception, CVAP software development was planned with a well-structured modular approach to minimize the cost and time associated with the V&V effort for upgrades and revisions. ***This ensures that new data and improvements to address emerging industry issues for check valves can be efficiently incorporated, verified, and validated in CVAP.***

The CVAP software input and output screens are heavily supported by graphics that illustrate critical features and dimensions of the valve being analyzed, valve orientation, flow direction, and elbow orientation. ***This user-friendly graphic interface eliminates mistakes and errors commonly made during calculations.***

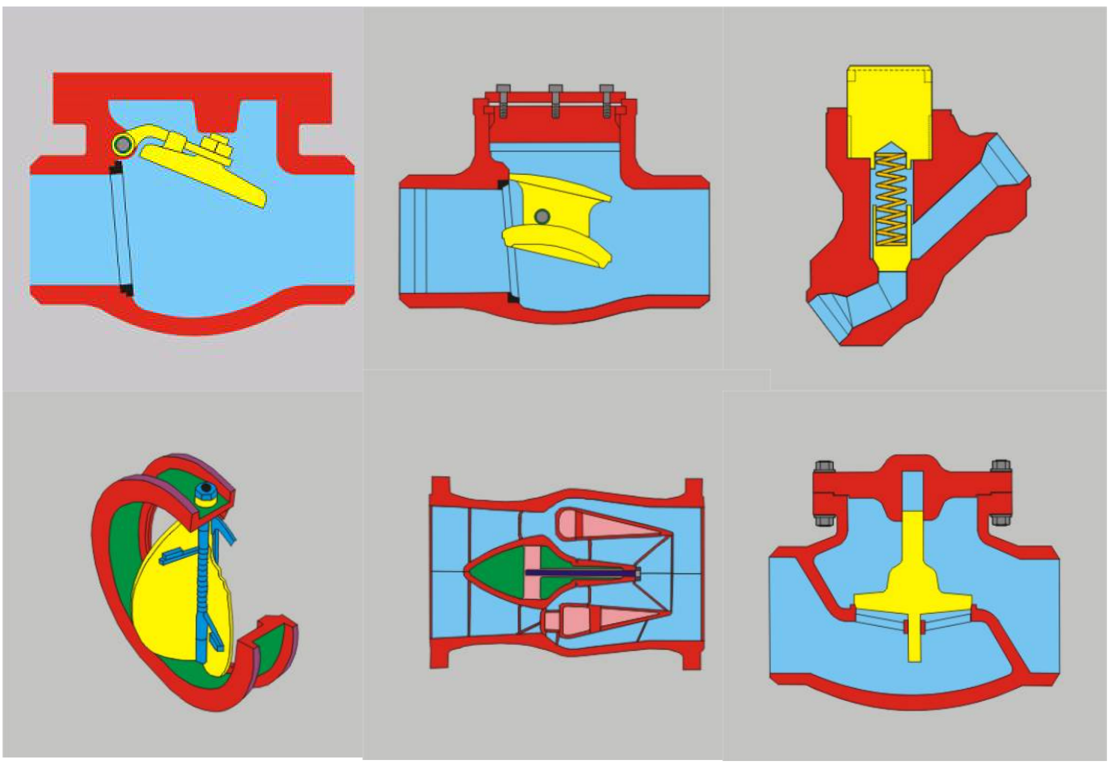
CVAP was developed by a team of Kalsi senior specialists who are recognized as leaders in the industry for technological advances in AOV, MOV, HOV, SOV and check valves. Our specialists have more than 20 years of continuous involvement in R&D to develop validated first principles models and software for valves and actuators to address generic industry-wide issues, including the EPRI MOV Performance Prediction Program and MOV guides. This experience is supplemented by performing design basis calculations and implementing MOV, AOV and Check Valve programs at more than 25 power plants.

CVAP Scope of Valves

CVAP software is capable of evaluating the following common types of valves and operators used in the U.S. nuclear power plants.

Valve Types

- Swing
- Tilt
- Double Disc
- Lift
- Nozzle



CVAP includes industry-established models for Swing, Tilt, Piston, Lift, Double Disc and Nozzle Check Valves

Key Calculations and Basis of Predictions

Calculations of check valve hinge pin wear and disc stud fatigue life for applications where flow is below minimum velocity (V_{min}) are based on several factors:

- Valve geometry and materials
- Valve installation including orientation and upstream piping disturbances
- Valve operating conditions under various plant operating modes and durations
- Severity and frequency of disc fluctuation.

Typical Applications

- Screen, group and prioritize check valves for maintenance using a sound engineering basis
- Track and trend check valve inspection and test results
- Reconstitute and optimize check valve maintenance through CVAP integration with nonintrusive diagnostics and/or visual inspection
- Assess the root cause of check valve malfunction
- Predict behavior of replacement valve candidates prior to selection and installation
- Evaluate impact of changes in valve application e.g, proposed piping and valve design modifications and altered system operating conditions

User Friendly Features

CVAP 4.0 offers the comprehensive predictive capabilities and new features that enable improved equipment condition monitoring and enhance analyst efficiency. These include:

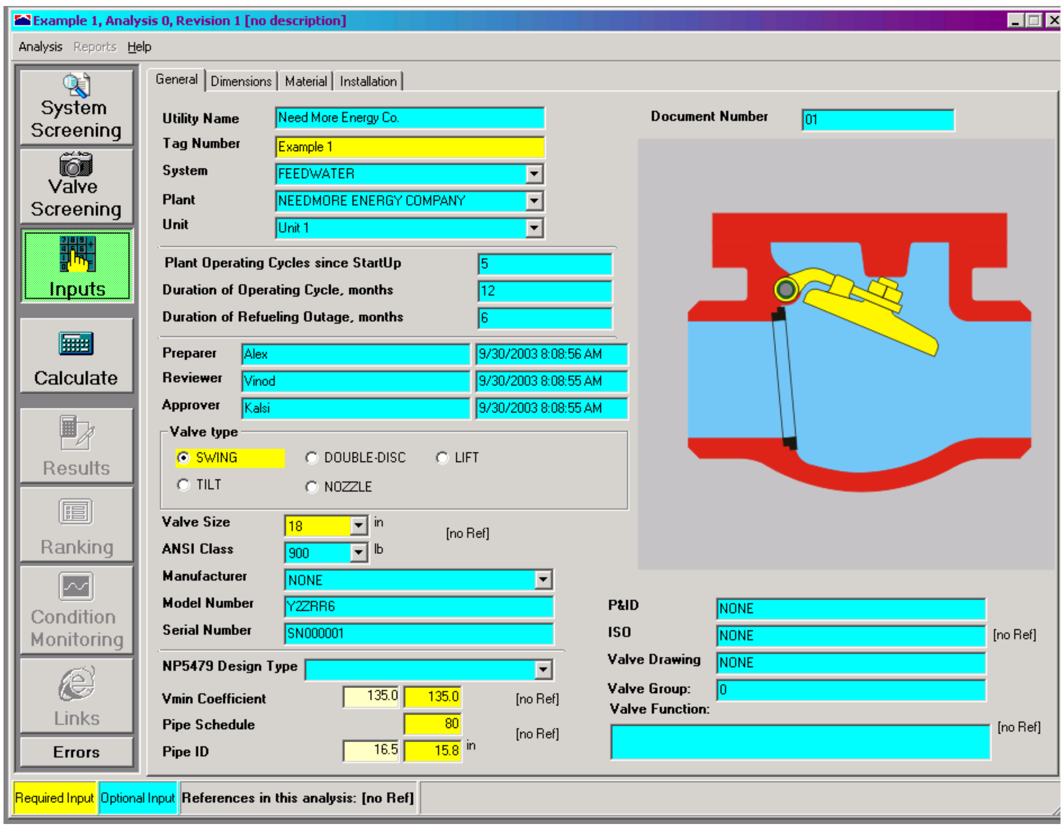
- System and valve screening templates to document valve selection basis
- Dimensional data scaling macro to enable information gathering and sharing over mutilple plant units
- Macro to estimate wear coefficient of hinge pin and bushing materials
- Vopen formula for double disc check valves
- Sensitivity analysis to post process disc stability, wear and fatigue analysis results to assess the the benefit of refining key inputs based on their influence on end results
- Condition monitoring screens to help track performance improvement activities and trend field measurements of wear and store screens captures of non-intrusive diagnostic test results, photographs from maintenance as well a program log
- Check valve ranking screen to combine and weight inputs from CVAP analysis, plant maintenance records, risk ranking, industry data and expert panel
- Compatibility with the latest PC operating systems
- Network compatibility to enable LAN usage and data sharing

Typical CVAP Screens

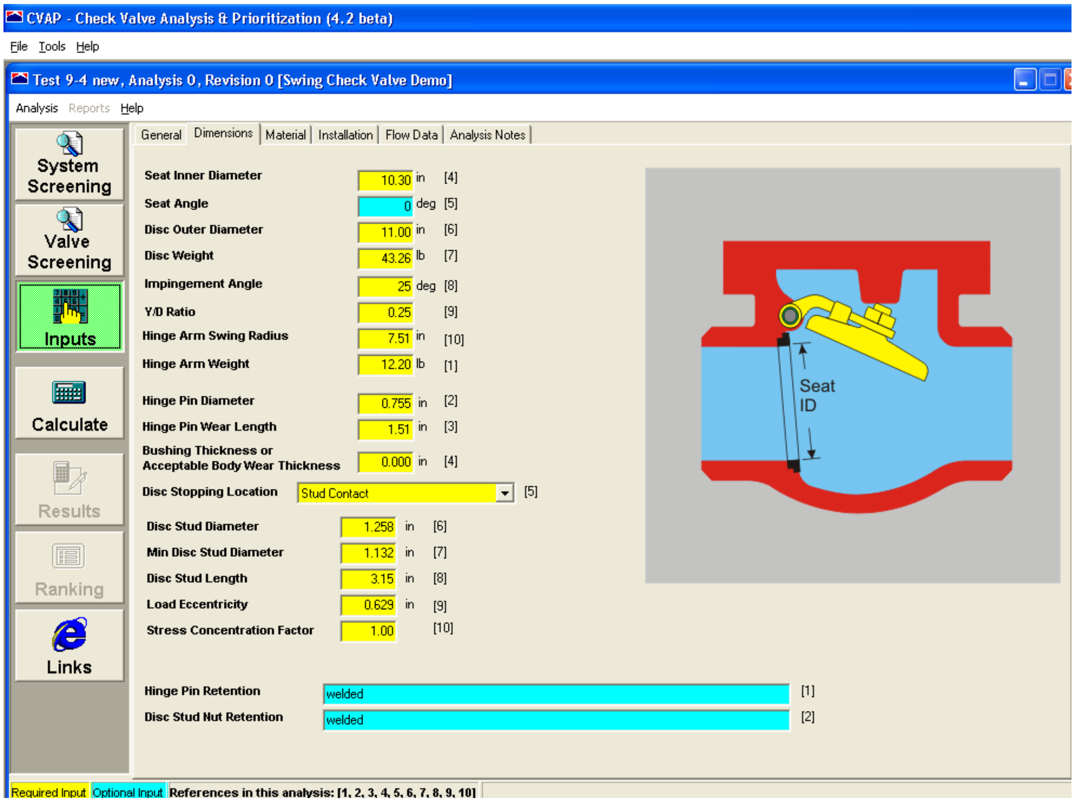
The CVAP software input and output screens are heavily supported by graphics that illustrate critical features and dimensions of the valve being analyzed, valve orientation, flow direction, and elbow orientation. ***This user-friendly graphic interface eliminates the potential for errors commonly made during calculations.***

Some examples of input and output screens follow:

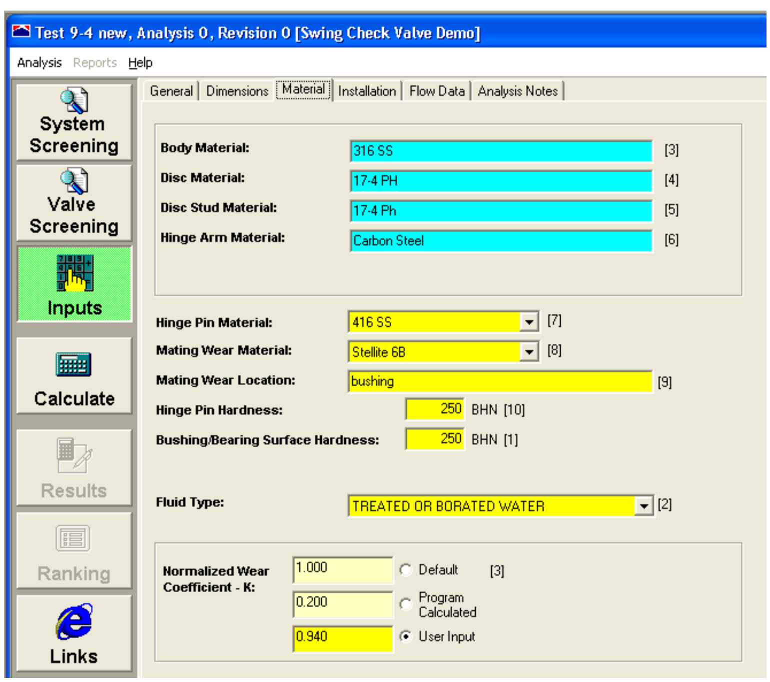
CVAP Main Menu



Dimensional Input Screen



Material Input Screen



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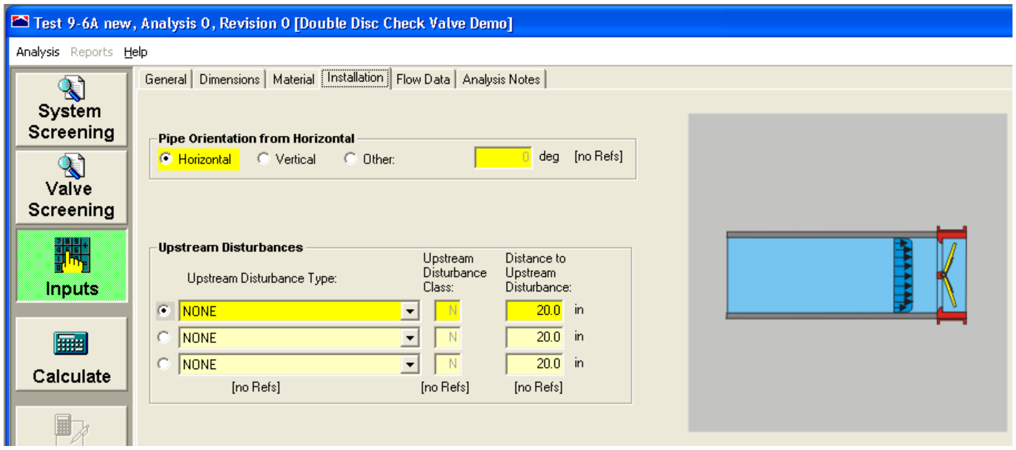
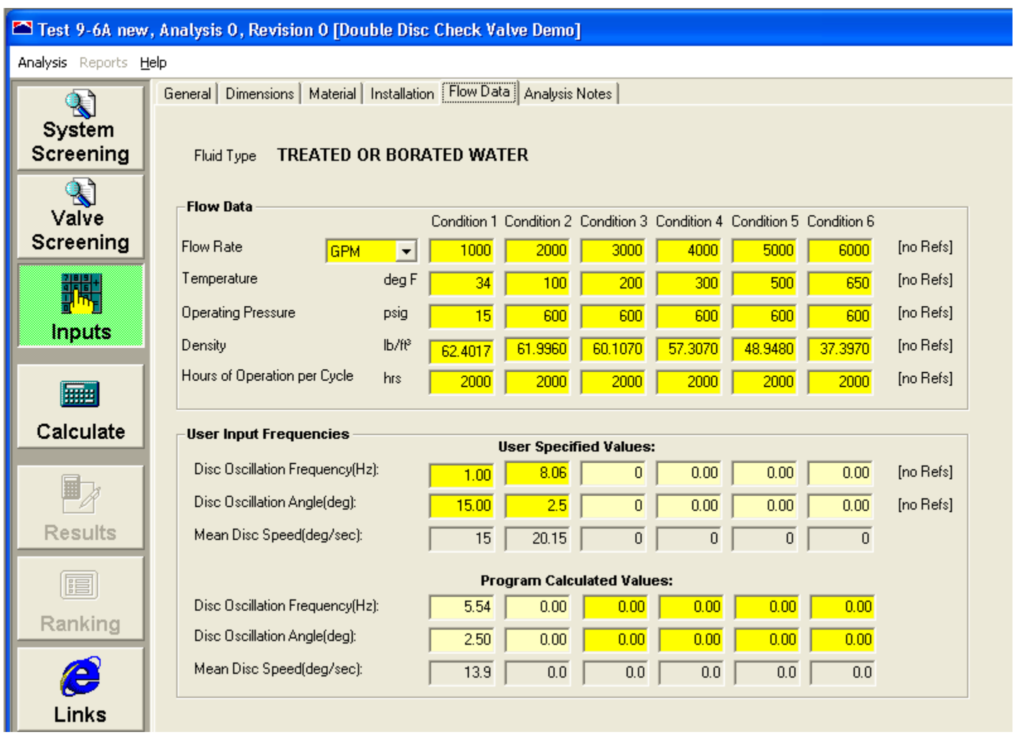
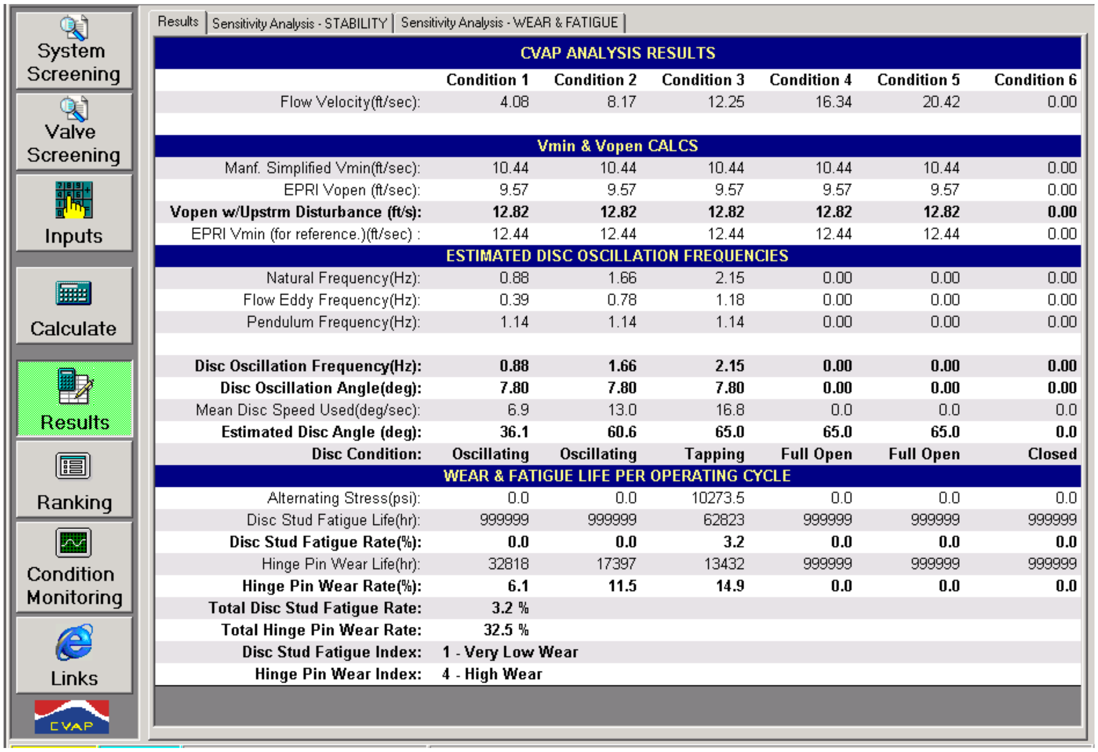
Installation & Flow Data Input Screens

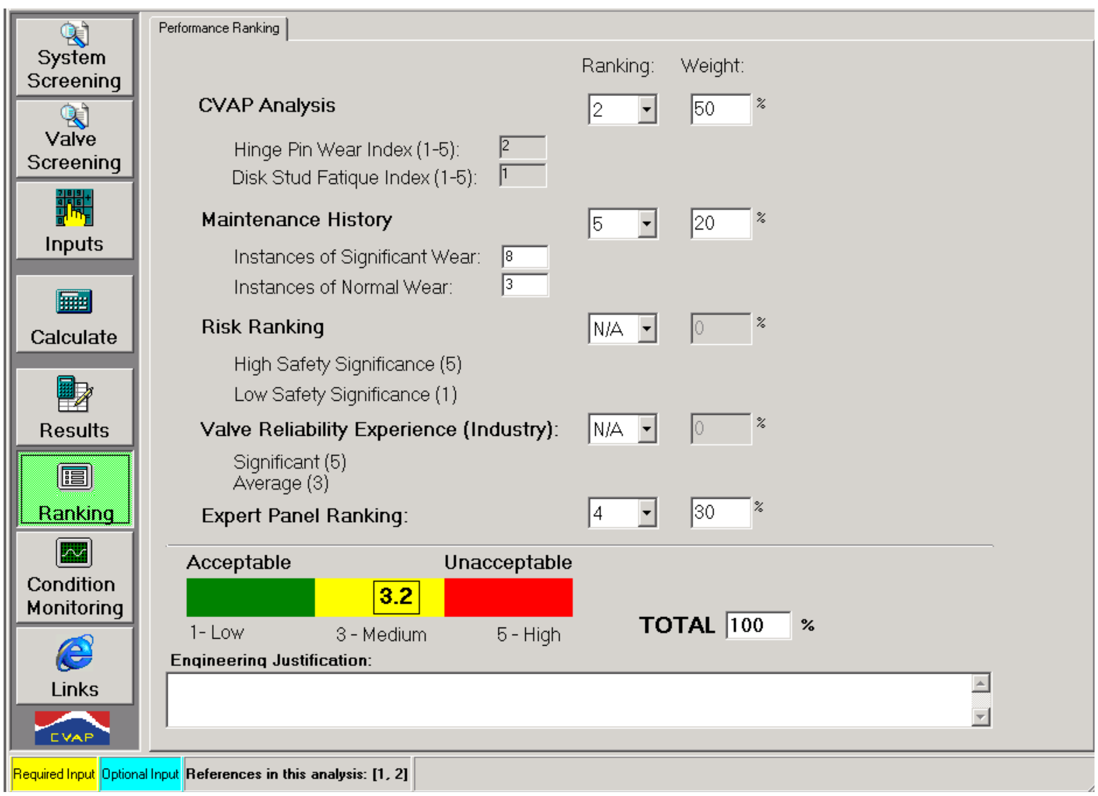




Results Screen



CVAP ANALYSIS RESULTS	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6
Flow Velocity(ft/sec):	4.08	8.17	12.25	16.34	20.42	0.00
Vmin & Vopen CALCS						
Manf. Simplified Vmin(ft/sec):	10.44	10.44	10.44	10.44	10.44	0.00
EPRI Vopen (ft/sec):	9.57	9.57	9.57	9.57	9.57	0.00
Vopen w/Upstrm Disturbance (ft/s):	**12.82**	**12.82**	**12.82**	**12.82**	**12.82**	**0.00**
EPRI Vmin (for reference.)(ft/sec) :	12.44	12.44	12.44	12.44	12.44	0.00
ESTIMATED DISC OSCILLATION FREQUENCIES						
Natural Frequency(Hz):	0.88	1.66	2.15	0.00	0.00	0.00
Flow Eddy Frequency(Hz):	0.39	0.78	1.18	0.00	0.00	0.00
Pendulum Frequency(Hz):	1.14	1.14	1.14	0.00	0.00	0.00
Disc Oscillation Frequency(Hz):	**0.88**	**1.66**	**2.15**	**0.00**	**0.00**	**0.00**
Disc Oscillation Angle(deg):	**7.80**	**7.80**	**7.80**	**0.00**	**0.00**	**0.00**
Mean Disc Speed Used(deg/sec):	6.9	13.0	16.8	0.0	0.0	0.0
Estimated Disc Angle (deg):	**36.1**	**60.6**	**65.0**	**65.0**	**65.0**	**0.0**
Disc Condition:	**Oscillating**	**Oscillating**	**Tapping**	**Full Open**	**Full Open**	**Closed**
WEAR & FATIGUE LIFE PER OPERATING CYCLE						
Alternating Stress(psi):	0.0	0.0	10273.5	0.0	0.0	0.0
Disc Stud Fatigue Life(hr):	999999	999999	62823	999999	999999	999999
Disc Stud Fatigue Rate(%):	**0.0**	**0.0**	**3.2**	**0.0**	**0.0**	**0.0**
Hinge Pin Wear Life(hr):	32818	17397	13432	999999	999999	999999
Hinge Pin Wear Rate(%):	**6.1**	**11.5**	**14.9**	**0.0**	**0.0**	**0.0**
Total Disc Stud Fatigue Rate:	**3.2 %**					
Total Hinge Pin Wear Rate:	**32.5 %**					
Disc Stud Fatigue Index:	**1 - Very Low Wear**					
Hinge Pin Wear Index:	**4 - High Wear**					



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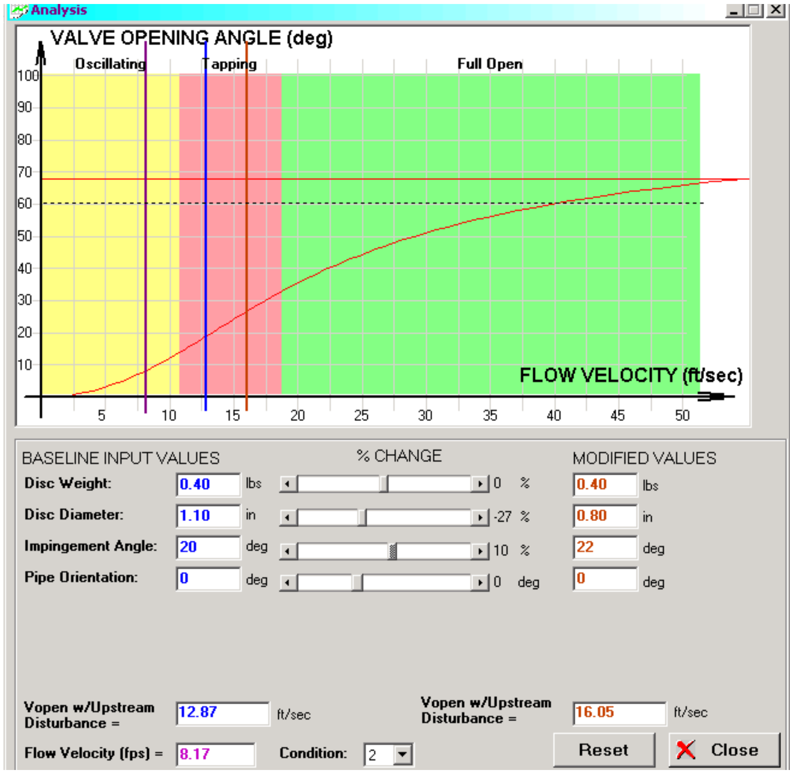
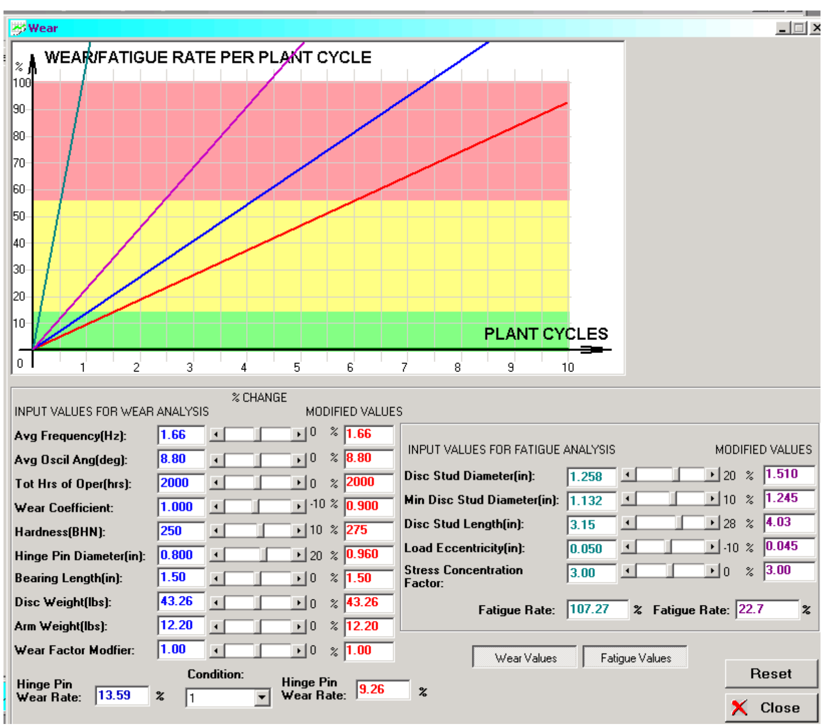
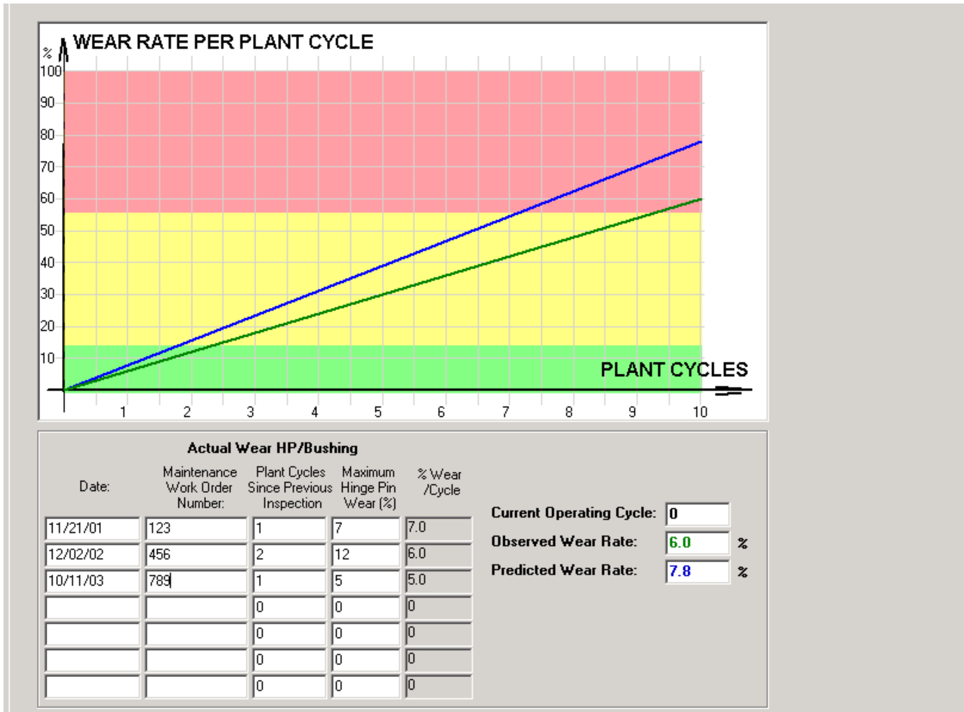
Post Processing & Sensitivity Analysis Screens





Condition Monitoring Screen



COMMAND Technical Description

The **Co**ndition **M**onitoring **Man**agement **D**atabase (COMMAND) software is designed to comprehensively meet the documentation and trending requirements of the ASME OM Code Mandatory Appendix II, "Check Valve Condition Monitoring Program." The COMMAND software addresses all program aspects including valve grouping, program analysis, optimization and performance improvement activity development, test/inspection intervals, trending and feedback, and corrective maintenance. In addition, the software includes a valve activity scheduling module, database query tools and hard-copy reports.

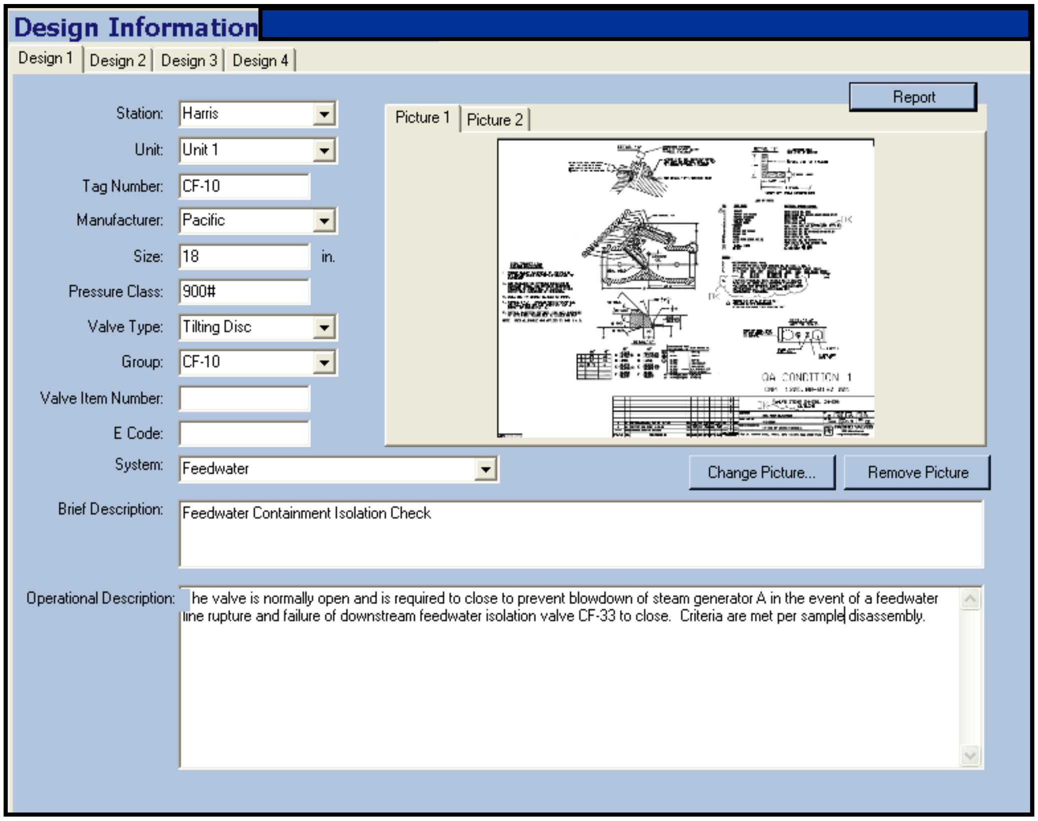


Figure 1: Sample COMMAND Input Screen

Individual valves can be viewed by plant system or condition monitoring (CM) group. Each group shows the grouping justification data along with a list of each valve in the group. For each valve, fundamental valve component and system design level data is stored along with the test and inspection activities. Each activity shows the type and description of activity, individual tasks and trendable attributes, test/inspection interval, and the test/inspection historical results. Numerical data trending allows the user to define acceptance ranges and select trendline projections to determine when an out of acceptance test is likely to occur so that test/inspection intervals can be optimized.

The scheduling module allows the check valve engineer to view the number of check valve activities targeted for a particular on-line work week or refueling outage to assist in planning resources (e.g. non-intrusive testing) or to manage the work load by adjusting test dates.

Reports include Appendix II grouping and analysis justification data, valve and group data, as well as activity trending and scheduling. Reports from user-defined queries are also available.

The COMMAND software provides a central collection point from which plant engineers can effectively manage their Appendix II CM program without having to develop and maintain a multitude of personal spreadsheets or databases. In addition, the software assists in succession planning and minimizes the transition time for new check valve program owners.

KEI Background Related to Check Valves

Valve design, analysis, testing, research and development, application, and problem solving are areas of special competence at Kalsi Engineering. As detailed in the resumes of the key personnel, the company has a technical staff with a very strong valve background. Our range of expertise in valves encompasses in-depth experience starting from the conceptual design stage through detail design, analysis, prototype development, testing, tooling and manufacturing, application engineering, troubleshooting, development of preventive maintenance programs, software development, and root cause analysis of valves in nuclear power systems and other industries.

Kalsi Engineering, Inc., is a consulting firm specializing in research and development, design, analysis, and testing of mechanical equipment. It is widely recognized in the U.S. and international nuclear power generation industries for its valve expertise and its commitment to technical excellence, high quality products, and professional integrity. Our staff has an outstanding background and record of accomplishments in understanding and developing solutions to problems in a wide range of applications in the nuclear power, pipeline, oil field, petrochemical, and aerospace industries. The company was founded in 1978, and has its corporate offices in Sugar Land, Texas (17 miles from downtown Houston). Our corporate offices are located in Houston, Texas; and we have clients in the U.S., Mexico, Canada, England, and Japan. The following sections provide details of our check valve related background.

Active Involvement in the Nuclear Industry Check Valve Issues Over the Past 23 Years

Kalsi Engineering has actively participated in and contributed to the nuclear industry group by making technical presentations, participating in subcommittees, and playing a leadership role in industry-significant NIC initiative. Kalsi Engineering is currently serving as the program manager for the Check Valve Training Program responsible for conducting all tests, evaluating results and conclusions, and developing the final report. This involvement provides Kalsi Engineering with a unique knowledge and continuity of experience in dealing with check valve issues.

EPRI Check Valve Application Guidelines Background

Under the sponsorship of all major U.S. electric power utilities and NSSS Owners' Groups, Kalsi Engineering was contracted by Electric Power Research Institute to develop a comprehensive guide for the application and use of check valves in the industry (EPRI's Report NP-5479, *Application Guidelines for Check Valves in Nuclear Power Plants*). This guide was the first such publication to fully address problems/failures related to check valves. It also included guidance regarding how to systematically review and improve the design, application, installation, inspection, testing, and maintenance practices to prevent check valve failures in various applications. Under this project, a large matrix of tests was performed to quantify the effect of variations in design, upstream flow disturbances, and flow conditions on the check valve performance and life.

We also contributed significantly to its revision, EPRI's Report NP-5479 Revision 1.0, *Application Guide for Check Valves in Nuclear Power Plants*, by including results from extensive wear and fatigue tests performed at Kalsi Engineering's flow loop.

INPO SOER 86-03 Experience

We have successfully completed check valve application reviews that meet the requirements of INPO SOER 86-03 and have provided solutions for problem valves at approximately 22 nuclear power plants. INPO has reviewed the results of our application review and called it **a model for the industry**. Our involvement has ranged from complete turnkey jobs for the whole project to providing technical support in developing solutions to problem valve installations. Our ability to effectively utilize in-house staff and to mobilize additional personnel when required allows us to respond to client needs on large-scale jobs.

There are several factors which we believe make Kalsi Engineering a very good candidate to effectively support check valve-related projects, as enumerated below:

In-Depth Knowledge of Various Manufacturers Recommendations

We have in-depth knowledge of check valve application guidelines and recommendations (if any) and their limitations given by all the major valve manufacturers including Rockwell, Crane, Anchor/Darling, Pacific, Velan, Westinghouse, Walworth, Powell, Atwood & Morrill, and Borg-Warner. By identifying the problems with some of the manufacturers' published data, Kalsi Engineering, Inc., was able to clearly identify the root cause of multiple check valve failures at San Onofre in the November 1986 event. More recently, Kalsi Engineering was involved in the root cause analysis of seating problems with certain Borg-Warner check valves, reported in NRC IN 89-62. Additionally, we are thoroughly familiar with Rockwell's Check Valve Application Manual and User's Guide (V-303) that follows the same basic approach in testing tilting disc and lift check valves that we used in the swing check valve matrix of tests under EPRI Guidelines.

Technical Experience Beyond the EPRI Guidelines

We continue to be involved in and at the forefront of the development and refinement of methodology to predict degradation of check valve internals. Kalsi Engineering has been awarded grants through the Small Business Innovation Research (SBIR) program to pursue our check valve research initiatives. The results of our Phase I and II efforts were published in April 1988 as NRC Report NUREG/CR–5159, *Prediction of Check Valve Performance and Degradation in Nuclear Power Plant Systems*. In 1990 as NUREG/CR–5583, *Prediction of Check Valve Performance and Degradation in Nuclear Power Plant Systems–Wear and Impact Tests*. This knowledge is continually integrated into our application review regimen, providing our clients with the most up-to-date information available in the industry.

Preventive Maintenance Based on Check Valve Analyses and Prioritization (CVAP) Program

We have developed the Check Valve Analysis and Prioritization (CVAP) program, which is based upon extensive information from the EPRI Check Valve Guidelines developed by Kalsi Engineering; our root cause analyses from many failures; and our continuing, systematic wear and fatigue testing on check valves at our flow test facility. CVAP allows us to perform a thorough, efficient, and very cost-effective analysis of various types of valves and provide *quantitative* information regarding relative degradation trends. This methodology has proven to be very useful in prioritizing valves from the standpoint of their adverse effect on safety and reliability as well as in developing a condition monitoring based preventive maintenance program with suitable maintenance/ inspection intervals for each valve.

Personnel with Strong Technical Background and Experience

Our key personnel have an average of 20 years of experience directly related to solving valve and check valve problems. This makes them immediately productive on your project with a very high efficiency in focusing their effort on those areas needing the most attention. See section on key personnel for details.

Experience in Performing Large-Scale, Plant-Wide Reviews

Kalsi Engineering has performed large-scale, plant-wide reviews of motor-operated valves and check valves at several nuclear power plants. The reviews have typically included valve populations ranging from 50 to 300 valves, with a population of 1758 valves at one plant. Our staff is well versed in managing projects of this scope in an efficient, cost-effective, and timely manner by providing a project team comprised of engineers and specialists with different levels of experience.

We have successfully performed comprehensive plant-wide check valve application reviews, at the following 17 plants:

- ***American Electric Power Co.:*** DC Cook
- ***Southern California Edison Co.:*** San Onofre Units 2 and 3
- ***Entergy Operation, Inc.:*** Waterford 3, Arkansas Nuclear One Units 1 and 2, Grand Gulf Nuclear Station and River Bend Station
- ***Nebraska Public Power District***: Cooper Nuclear Station
- ***Florida Power and Light Co***.: St. Lucie Units 1 and 2; Turkey Point Units 3 & 4
- ***Houston Lighting and Power***: South Texas Project
- ***Texas Utility***: Comanche Peak Nuclear Station
- ***Toledo Edison Company***: Davis Besse Plant
- ***Illinois Power Company***: Clinton Power Station

We have provided solutions for problem valves at several nuclear power plants in addition to those listed above. This combined with out in-depth knowledge of the various manufacturers' recommendations and our background in non-intrusive inspection and monitoring methods makes our team highly productive on plant check valve program development projects.

Credibility with NRC

Because of our fundamentally sound and strong technical background in analysis as well as design and testing of mechanical equipment, Kalsi Engineering has established an excellent credibility with the utilities and NRC over the years. This has been a significant factor in obtaining NRC concurrence on a number of critical industry-wide technical issues where even the equipment manufacturers' were unable to provide a technical basis acceptable to NRC.

KEI Project Experience Related to Check Valves

Since 1985, Kalsi Engineering has applied and enhanced CVAP to perform a wide range of check valve evaluations including:

- Development of check valve preventive maintenance programs
- Root cause analysis of check valve failures and premature degradation
- Testing of check valves to determine V_{min}, C_V, and flow performance
- Design analysis and equipment modification
- INPO SOER 86-03 check valve application reviews
- Selection of replacement valves based on analysis and testing
- Development of dimensional inspection/acceptance criteria

Our list of clients includes: American Electric Power Co., Nebraska Public Power District, Florida Power & Light, Houston Lighting & Power, Entergy Operations, Texas Utilities, Illinois Power, Commonwealth Edison, Toledo Edison, Carolina Power & Light, Virginia Power, Northeast Utilities Service Company, Southern California Edison Company, and Duke Power Company, as well as many commercial and legal clients in projects related to product liability, expert testimony, and failure analyses. The following are descriptions of some typical check valve projects.

CLIENT: **Progress Energy**

PROJECT: **Check Valve Application Review**

SCOPE: Kalsi Engineering evaluated and prioritized 87 valves installed at Harris plant, with specific recommendations for maintenance intervals. This effort saved Harris at least $350,000 in critical path time, not including manpower resources.

CLIENT: **Entergy Operations, Inc.**

PROJECT: **River Bend Station Check Valve Program Development Using CVAP**

SCOPE: The objective was to conduct a comprehensive screening/evaluation of all 1,758 check valves installed at the River Bend Station to identify and rank potential bad actors without sacrificing conservatism or reliability. A systematic approach was developed to identify those valves that require a detailed evaluation based on each valve's safety function, importance to power generation, and importance to personnel safety. A comprehensive predictive analysis was performed on the 580 valves thus identified to determine their relative propensity for degradation. Factors considered included valve design, materials of construction, system characteristics, and operating flows under all modes of plant operation. A prioritized ranking of check valves was developed based on the results of the CVAP analyses and review of RBS's check valve maintenance history. This prioritized list provides a systematically planned basis for the selection of suitable inspection/maintenance/ testing intervals.

CLIENT: **Entergy Operations, Inc.**

Grand Gulf Nuclear Station

PROJECT: **Verification of Root Cause of Failure-to-Close and Determination of Optimum Disc Opening Angle Using CFD**

SCOPE: A 24-inch tilting disc check valve installed in a reactor feedwater line at Grand Gulf Nuclear Station failed to close when reverse flow occurred due to a feedwater pump trip. The objectives of this study were to validate the hypotheses that the root cause for this failure was an increased disc opening angle and rapid flow reversal, and to determine the optimum disc angle, "the angle that provides an assurance of closure on reverse flow without the introduction of excessive pressure loss during forward flow". These objectives were met by performing a matrix of analysis using computational Fluid Dynamics (CFD) methodologies to simulate the actual valve. This eliminated the need for costly full-scale or scale-model testing.

CLIENT: **Carolina Power and Light Company**
Robinson Nuclear Station

PROJECT: **Root Cause Analysis of Main Steam Isolation Valve's Failure to Close**

SCOPE: During a scheduled refueling outage, the MSIV was signaled to close after the steam generator trip; it failed to close. It was found that the disc was stuck open, i.e., the disc outside edge was wedged into the neck area of the valve body. Kalsi Engineering Inc. performed analysis to investigate the disc-binding problem to determine the root cause, evaluate the impact on normal operating conditions, and recommend options to solve the problem. The goal was to understand the importance of each factor and to determine the root cause without detailed and time-consuming quantification. Factors analyzed included disc-to-body clearance, thermal binding, pressure-induced binding, friction variation, thrust components, and disc wedging and unwedging forces. The results of these analyses identified the relative contribution of each factor to the root cause of disc binding.

CLIENT: **Northeast Utilities Services Company**
Millstone Unit 1

PROJECT: **Condition Assessment of Tilt Disc Check Valve**

SCOPE: 1-CU-29 is an 8-inch tilting disc check valve located in the reactor water clean-up system. It had been in continuous operation for 24 years. The objective of this analysis was to assess the amount of hinge pin and bushing wear, and to predict the remaining life of dependable disc travel from open to closed position. CVAP was used to predict hinge pin and bushing wear, and program predictions were compared with inspection findings. A trigonometric analysis based on static loads was performed to estimate the wear threshold at which the disc was likely to hang open during the closing stroke.

CLIENT: **Southern California Edison Company**
San Onofre Nuclear Generating Station

PROJECT: **4-Inch Tilting Disc Check Valve Chatter**
Root Cause Analysis and Solution

SCOPE: SCE had been experiencing check valve chatter in the auxiliary feedwater (AFW) turbine steam supply system at SONGS Units 2 and 3. Kalsi Engineering was contracted to analyze the results of the 1993 test program to determine the root cause and to recommend changes or solutions to eliminate the check valve chatter.

To determine the root cause of valve chatter, the test data was reviewed in detail, a mechanism was postulated for the chatter, and a mathematical model was derived for the postulated mechanism. The model was used to explain and understand the observed valve chatter characteristics. Several schemes to eliminate chatter were also evaluated by use of the model. Two solution concepts were recommended for implementation into the system, the final choice depending on system constraints and preferences.

CLIENT: **Nebraska Public Power District**

PROJECT: **Cooper Nuclear Station Check Valve Program Development**

SCOPE: The objective of this project was to develop new procedures and upgrade the check valve program by performing a comprehensive evaluation of all 1,496 check valves installed at Cooper Nuclear Station. To identify valves in need of detailed evaluation, a systematic failure-mode-and-effect analysis approach was developed based on each valve's safety function, importance to power generation, and importance to personnel safety. A comprehensive evaluation was performed on 472 selected valves using our Check Valve Analysis and Prioritization (CVAP) program. CVAP incorporates the technical recommendations and procedures given in EPRI's *Check Valve Application Guide* [NP-5479] and reports entitled *Prediction of Check Valve Degradation in Nuclear Power Plant Systems* [NUREG/CR-5159 and NUREG/ CR-5583].

Cooper Nuclear Station's maintenance history records, NPRDS reports, and NCRs were reviewed and integrated with analysis results to develop suitable recommendations for inspection intervals and maintenance. A review of nonintrusive diagnostic technologies was performed to assess the performance of check valves, and recommendations for integrating the use of dual-sensor non-intrusive testing devices with visual inspection were provided. General acceptance criteria for inspecting valve internals were also developed.

CLIENT: **Florida Power & Light Company**

PROJECT: **Check Valve Application Review to Meet INPO SOER 86-3 Requirements**

SCOPE: Kalsi Engineering performed a full check valve application review of over 600 valves at FP&L's St. Lucie Units 1 & 2 and Turkey Point Units 3 & 4. The methodology used in the review utilized the Check Valve Application Program, CVAP, which has been developed by Kalsi Engineering to perform thorough, efficient, and cost-effective reviews on a large variety of valves with different types of upstream disturbances and variable flow conditions present in the nuclear power plants. Our check valve review program was reviewed by INPO and acknowledged as a "model" for the industry.

CLIENT: **Houston Lighting & Power Company**

PROJECT: **Check Valve Application Review to Meet INPO SOER 86-3 Requirements**

SCOPE: Kalsi Engineering supported HL &P's INPO SOER 86-3 check valve application review effort for South Texas Project, Unit 1. Two hundred valves were evaluated and prioritized using our Check Valve Application and Prioritization program (CVAP), with specific recommendations for maintenance intervals.

CLIENT: **Middle South Utilities/Bechtel**

PROJECT: **Check Valve Application Review to Meet INPO SOER 86-3 Requirements**

SCOPE: Kalsi Engineering supported Middle South Utilities' check valve application review effort for Grand Gulf Unit 1. One hundred sixty valves were evaluated and prioritized using our Check Valve Application and Prioritization program (CVAP), with specific recommendations for maintenance intervals. In this project, Bechtel was responsible for gathering all the data and Kalsi Engineering was responsible for performing the detailed application review and making specific recommendations.

CLIENT: **Texas Utilities Electric Company**

PROJECT: **Check Valve Application Review and Development of Preventive Maintenance Program**

SCOPE: Kalsi Engineering provided turnkey services for T.U. Electric in the development of a check valve preventive maintenance program Comanche Peak Steam Electric Station. Approximately 200 valves were evaluated and prioritized using our Check Valve Application and Prioritization program (CVAP), with specific recommendations for maintenance intervals.

Check Valve Related References and Other Significant Documents Developed by Kalsi Engineering, Inc.

Kalsi Engineering staff has contributed significantly towards the state-of-the-art in check valve performance predictions and improvements by publishing the following technical papers and guidelines.

- Contributed to *Enhancing Your Check Valve Program by invoking Appendix II Condition Monitoring* (with Mike Robinson, K&M Consulting and the Nuclear Industry Check Valve Group), Proceedings of the Eight NRC/ASME Symposium on Valve & Pump Testing, August 2004.
- *Check Valve Wear Quantification for Improved Cost Effectiveness and Plant Reliability*, Proceedings of the 9th EPRI Valve Technology Symposium, August 2003.
- *Root Cause Analysis and Elimination of Check Valve Performance Problems by CFD*, Proceedings of the Fifth NRC/ASME symposium on Valve and Pump Testing, NUREG/CP, July 1998
- *CFD as a Tool for Check Valve Root Cause Analysis and Performance Improvement*, EPRI Valve Symposium, 1997
- *Application Guidelines for Check Valves in Nuclear Power Plants, Revision 1*, EPRI NP-5479, June 1993
- *Prediction of Check Valve Performance and Degradation in Nuclear Power Plant Systems–Wear and Impact Tests*, NUREG/CR-5583, April 1990
- "Integrating the Check Valve Application Review with Preventative Maintenance Programs," ASME Paper 89-JPGC/NE-2
- "Improving Check Valve Reliability through Research Regarding Degradation of Internals," *Transactions of the Seventeenth Water Reactor Safety Information Meeting*, NUREG/CP-0104, October 1989
- "Prevention of Water Hammer Problems by Eliminating Check Valve Degradation," *First International Symposium on Power Plant Transients - 1988 FED-Vol. 67*, Papers from Winter Annual Meeting of ASME, 1988
- "Guidelines for the Application and Use of Valves in Power Plant Systems," presented at the EPRI Power Plant Valves Symposium, Charlotte, NC, October 1988
- "Effect of Upstream Elbow on Swing Check Valve Performance," *Proceedings of the 1988 Joint ASME/ANS Nuclear Energy Conference*, ASME Publication No. 100267, April 1988
- "Swing Check Valve Disc Stability Under Turbulence," *Proceedings of the 1988 Joint ASME/ANS Nuclear Energy Conference*, ASME Publication No. 100267, April 1988
- *Prediction of Check Valve Performance and Degradation in Nuclear Power Plant Systems*, NUREG/CR-5159, April 1988

- *Application Guidelines for Check Valves in Nuclear Power Plants*, EPRI NP-5479, January 1988
- "Plant Availability Improvement by Eliminating Disc Vibrations in Swing Check Valves," ASME Paper 86-JPGC-NE-6
- "Finite Element and Experimental Stress Analysis of 48-Inch Swing Check Valve for Alaskan Pipeline," ASME Paper No. 74-114; presented at the Second National Congress on Pressure Vessels and Piping Technology, San Francisco, June, 1975

CVAP & COMMAND Licensing Options and Cost

See Cost Proposal

In summary, we believe that the technology and user-friendly features built into these software packages will provide you with an accurate and reliable, cost-effective tool to develop and maintain your check valve program. Kalsi Engineering's proven technical record of performance and continued stability of the organization ensures that Kalsi valve specialists will address all your CVAP & COMMAND technical support requirements promptly.